

Modeling the SAR Signature of Nonlinear Internal Waves

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LONG-TERM GOALS

The long-term goal of this project is to develop a forward model that predicts the Synthetic Aperture Radar (SAR) signature of Non-Linear Internal Waves (NLIWs) under a range of environmental conditions.

OBJECTIVES

The objectives of this project are to understand, quantify and model the factors that influence the SAR signature of internal waves (IW) using *in situ* and remote measurements. To accomplish this we will determine the factors that impact the both the surface roughness and the corresponding radar backscattering cross section. Two factors that influence surface roughness that have not been included explicitly in earlier models for predicting the SAR signature of IWs are compound modulation and breaking waves. We are developing models for both of these contributions.

APPROACH

The technical approach pursued in this work is to implement an enhanced form of the model developed by Lyzenga and Bennett (1988) (L&B). The L&B model uses the action balance equation to model the spatial/temporal changes to the wave action spectral density produced by interactions arising between surface waves and currents generated by the passage of an IW. The L&B model predicts the modulated surface roughness and corresponding backscattering cross section. The enhancements we are incorporating are to include the effects of compound modulation (NLIW modulation of intermediate-scale waves which in turn modulate centimeter-scale waves) and breaking waves into the framework of the L&B model. Though the current implementation of this model uses the Pierson-Moskowitz spectrum, future versions we are developing will use other ocean wave spectral models. In addition, we are taking advantage of recent developments in numerical methods to make this implementation of the model both more computationally efficient and more robust.

WORK COMPLETED

In support of model development and validation we have produced a database that includes collocated satellite data (ENVISAT, ERS, SAR imagery as well as QuikScat wind vector maps), ship-based radar measurements (from the US-based R/V Revelle and the Taiwanese ship OR3), and moored thermistor chain (S7) measurements acquired in the South China Sea during the intensive data collection conducted in the summer of 2005. Though the experiment was conducted over the course of a few

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months, there were a surprisingly limited number of cases where there were simultaneous ship-based and satellite-based observations of IWs. One such case, however, will be shown in the following section. In addition, we have developed a web-based version of the L&B model that will be made available to the community for use. As future versions of the model are developed, this web-based version will provide a useful platform for testing, verifying and comparing models developed by various participants in the project. Preliminary results for this model are shown in the following section.

RESULTS

We have successfully and efficiently implemented the L&B model for surface wave-internal wave interaction. To express the modulation of surface waves by currents from NLIWs we consider the ratio of A/A_0 , where A_0 is the equilibrium spectral density for surface waves. Examples of A/A_0 for waves of various scales are shown in Figures 1 and 2.

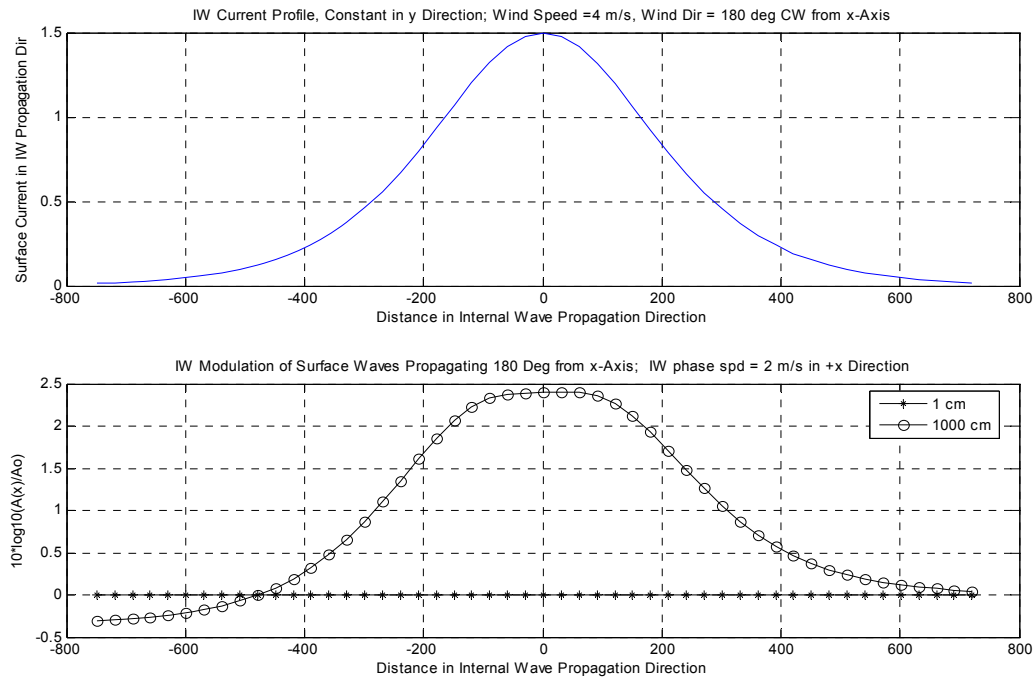


Figure 1. Modulation of equilibrium spectral density by currents due to NLIWs. The upper panel shows the distribution of surface current speeds in the direction of propagation of the NLIW, assuming that the wind speed is 4ms⁻¹, and the NLIW propagation is directly opposing the wind direction. (cont'd on next page)

The lower panel shows the modulation (A/A_0) experienced by surface waves of 1 cm (*) and 10 m (o) due to interaction with the NLIW. This clearly shows that the 1cm (Bragg-scale) waves experience negligible modulation, whereas the 10m waves experience significant modulation.

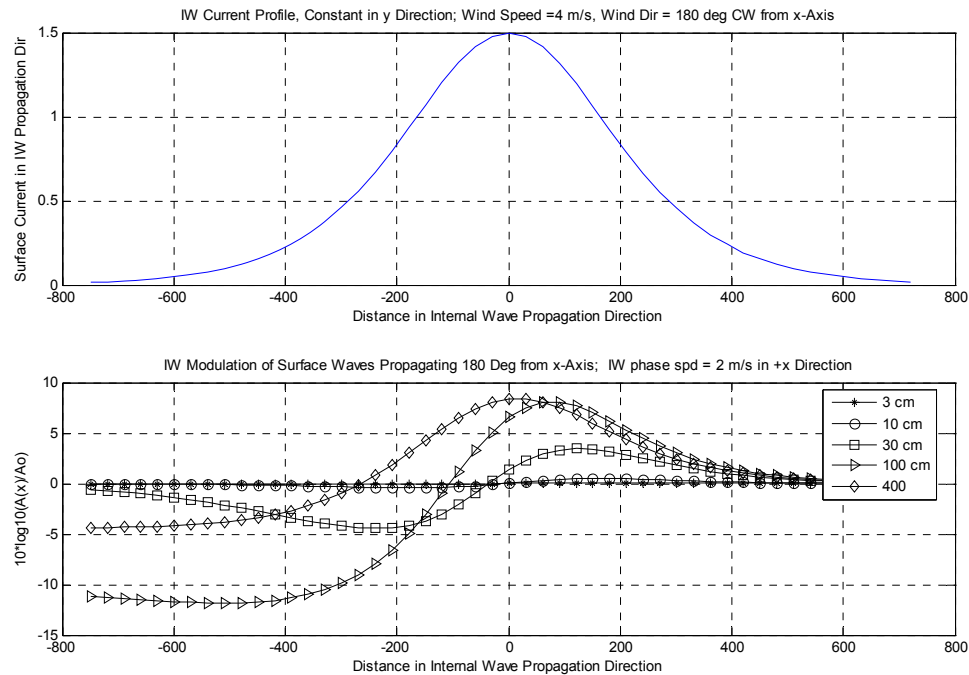


Figure 2. Here consider modulation experienced by waves at scales between the two extremes presented in Figure 1. The upper panel shows the surface current distribution in the direction of propagation of the NLIW, for same conditions as in Figure 1 (NLIW propagating opposite to wind direction; 4ms-1 wind speed). The lower panel shows the modulation (A/A_0) experienced by surface waves of 3 cm (*), 10 cm (o), 30 cm (square), 1m (triangle) and 4 m (diamond) due to interaction with the NLIW. Again the Bragg-scale waves (< 10 cm) experience negligible modulation, whereas the waves of 0.3, 1 and 4m experience significant and progressively increasing modulation.

We have considered several different scenarios in which the wind speed and direction, IW propagation speed and direction are varied, including aligned and opposing (shown above) wind and IW propagation, as well as various oblique angles of interaction. We are currently investigating scenarios where surface wave trapping and blocking occurs, and are augmenting the L&B model to include breaking wave effects and compound modulation.

In addition, we have worked carefully to find cases of coincident SAR and ship-based radar measurements of NLIWs. Ship-based radars have a limited range ($O(10$ km)) relative to the scale of satellite imagery, so though considerable SAR imagery containing NLIWs were acquired in the South China Sea during the summer of 2005, the number of collocations is extremely limited due to constraints including time and location of satellite overpasses, direction of ship heading and radar look direction. Figures 3 and 4 provide examples of collocated satellite- and ship-based observations of IWs and features of interest, one acquired from the OR3 and one acquired from the Revelle.

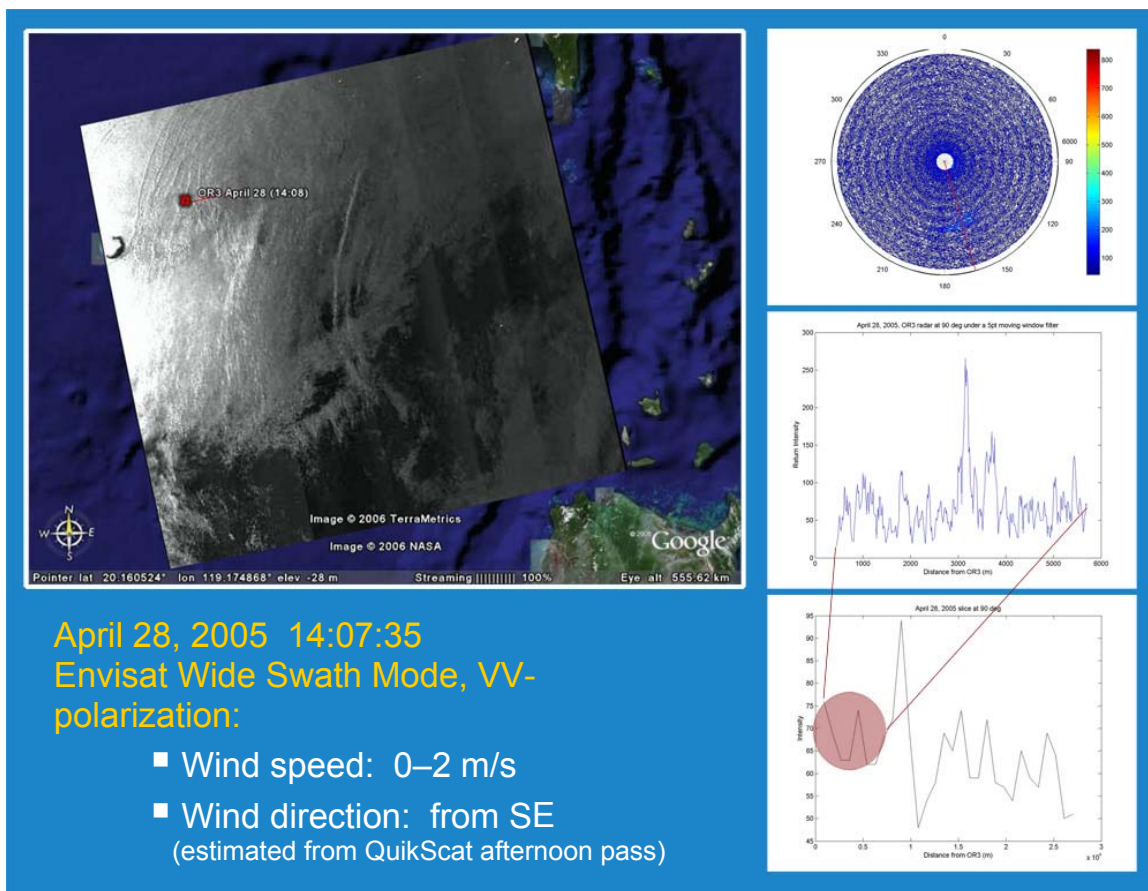


Figure 3. This figure shows collocated, satellite-based SAR and ship-based radar measurements of an internal wave in the South China Sea. This C-band, vertically polarized ENVISAT image was acquired April 28, 2005; wind speed was 0 – 2 ms⁻¹ and from the SE, as estimated from a contemporaneous QuikScat overpass. The location of the OR3 is indicated in red in the upper left corner of the image. The three panels on the right of the figure show (top) an X-band ship-based radar measurement obtained from the OR3; (middle) an intensity plot taken in the direction of the IW (indicated by a red line in the top panel) that clearly shows the presence of an IW; (bottom) an intensity plot taken from the ENVISAT image along the direction indicated by the red line originating at the location of the OR3. The red shaded area shows the portion of the satellite-based intensity plot overlapping with the intensity plot for the ship-based radar. Though the resolution of the ENVISAT image is, as expected, much coarser than the ship-based radar, the same IW can still be clearly observed in both plots.

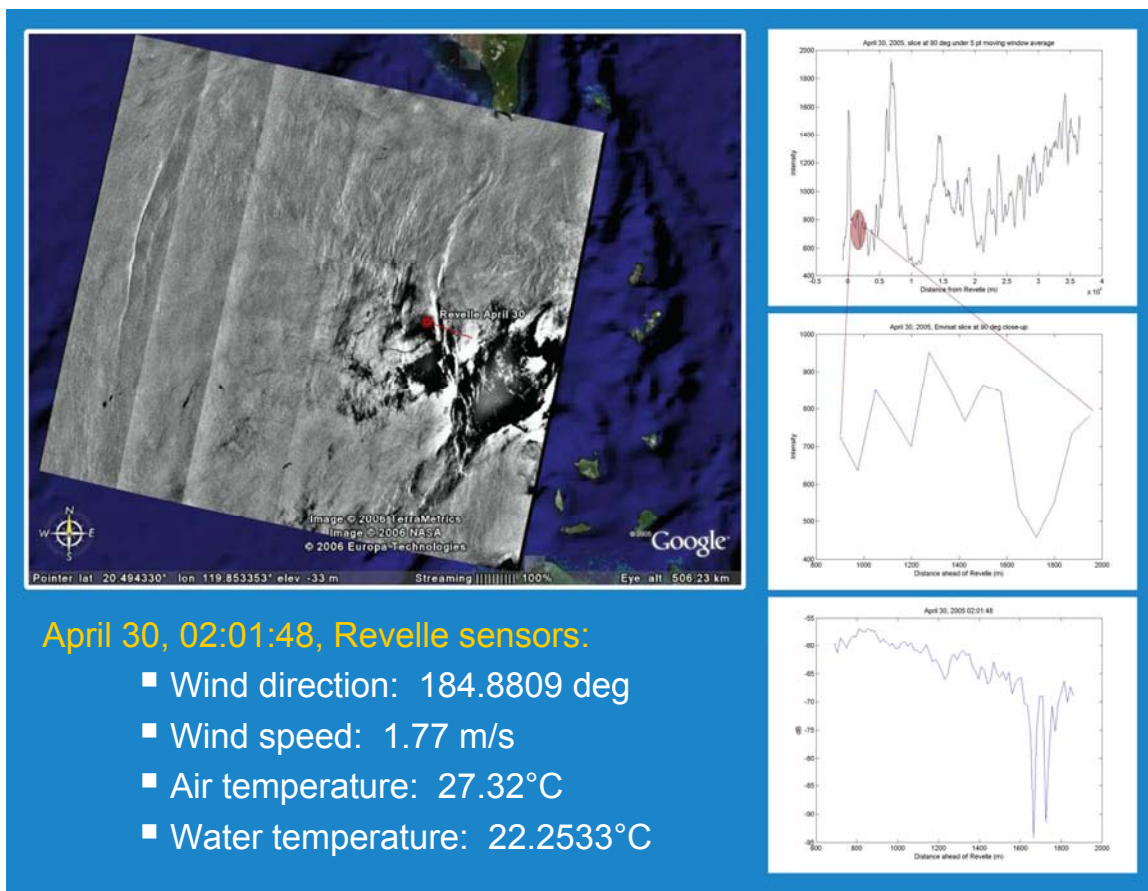


Figure 4. This figure shows collocated, satellite-based SAR and ship-based radar measurements of a feature of note (but not an IW) in the South China Sea. IWs are clearly evident in the ENVISAT image from April 30, 2005, but were not within the range of the ship-based radar. Wind speed was 1.77 ms⁻¹ and from the S, and was measured by ship-based sensors on board the Revelle. The location of the Revelle is indicated in red to the right of the center of the image. The three panels on the right of the figure show (top) an intensity plot taken from the ENVISAT image along the radar look direction, indicated by a red line originating at the location of the Revelle. As in Figure 3, the red shaded area shows the portion of the intensity plot overlapping with the intensity plot for the ship-based radar. (middle) Here we see a subset of the intensity plot corresponding to the radar range and look direction (indicated by a red slice in the ENVISAT image); (bottom) an X-band ship-based radar measurement of the feature of note obtained from the Revelle.

IMPACT/APPLICATIONS

The forward model being developed in this effort will be a key component of a capability for predicting and identifying IWs in satellite-based SAR imagery.

RELATED PROJECTS

I am closely collaborating on this project with my colleague Dr. Bill Plant of APL-UW. I am also collaborating with other colleagues within the ocean remote sensing community, notably Dr. David Lyzenga from the University of Michigan and Dr. Chris Jackson from Global Ocean Associates. I am also collaborating with Drs. Frank Henyey and Ren-Chieh Lien from APL-UW, who have consulted with me on project-related issues and have shared data with me obtained from the OR3, respectively. Dr. Steve Ramp of the Naval Postgraduate School has provided me with measurements obtained from the moored thermistor chain S7, that are being analyzed in this effort as well.

PUBLICATIONS

Lettvin E., SAR Observations and Models of Nonlinear Internal Waves in the South China Sea, IGARSS 06 Conference Proceedings